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Tomato Harvesting in Greenhouse Considering the Effect of Sunlight

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Abstract

Tomato is one of the important fruit vegetables and most tomatoes are produced in the greenhouses, or large-scale farms, where the high temperature and humidity, and long harvest age force the farmer heavy works. To develop the tomato harvesting robot, many research issues exist such as manipulator design, end-effector design, collaborative behavior, artificial intelligence, motor control, image processing, target recognition and so on. For the operation in greenhouses, the recognition system with color constancy under sunlight is necessary. In the harvesting, tomatoes should be handled gently for less damages so that the soft handling end-effector is needed. In this paper, we introduce the system configuration of the robot and the experiments conducted to solve the problem in the greenhouse.

Keywords: *Tomato-Harvesting Robot, End-effector, Color constancy, Sunlight*

1. Introduction

In agriculture, the aging and depopulation of farmers cause the shortages of farmers and manpower. The shortage of agricultural manpower has become serious problems in Japanese agriculture [1]. According to the report from the Ministry of Agriculture, Forestry and Fisheries (MAFF), the number of fulltime agricultural workers decreased by 33.6% during the past 10 years, from about 2.05 million in 2010 to about 1.36 million in 2020. The percentage of senior workers (over 65 years old) is increasing.

There are many reasons, such as cost-efficiency of the robotization, safety of the works using robots, difficulty of outdoor operations, and knowledge transfer problem from farmers to computer. As one of solutions for the problems, robot technology into the agriculture is expected to contribute to the labor-saving, improvement of production, production line automation, and also the management toward smart-agriculture.

We organize the Tomato-harvesting-robot competitions [2][3] since 2014 with the aim to foster the automation of tomato harvesting and invite young robotics researchers to agriculture. We select tomato as the target fruit as tomato is one of most important fruit vegetables. Most tomatoes are produced in the greenhouses, or large-scale farms, where the high temperature and humidity, and long harvesting force the farmers heavy works. A soft handling end-effector is needed without any damage both the surface and inside.

In addition, sunlight changes brightness and color temperature and give large influence on vision system, so color constancy is also one of key technologies [4][5].

In this paper, we introduce the tomato harvesting robot, the end-effector, and discuss the images in the greenhouse by comparing with and without the polarizing films to a camera and a lighting system.

2. Tomato harvesting robot

2.1. *Basic robot configuration and behavior*

The tomato harvesting robot is shown in Fig. 1. The robot mainly consists of mobile mechanism, a vision system, an orthogonal type manipulator with an end-effector, and a control computer (see details in [6]-[8]). The robot goes along the rails until a tomato is detected using the RGB-D camera. When a tomato is detected, the robot stops going and calculate the position of each tomato, the tomato maturity, and the harvesting order of tomatoes. Then, the manipulator approaches to the first priority target tomato and harvests it one by one with an end-effector. The obtained tomatoes move to the box through the tube attached beneath the end-effector.

2.2. *End-effector for tomato harvesting*

The harvesting is required not to give damages not only their surface but also inside. We developed a suction cutting type end-effector [8] as shown in Fig. 2. The end-effector has the cylindrical shape and consists of three modules, suction, cutting and fruit guiding modules. The suction module uses vaccume force to hold the tomato in the right position for cutting and not to give damages to the surface by preventing from grasp of the tomato. The cutting module cuts the stalk of tomato and harvests the tomato with remaining its calyx. The cutting module consists of a blade fixed to the upper edge and a U-shaped finger which is rotated by a motor to cut the stalk. Inside the module, a pair of a laser and a photoresistor is attached to check the tomato fruit is in the right position. The fruit guiding module transports the harvested tomatoes to the harvest-box and whose shape is an acrylic pipe with split lengthwise. The upper half of the pipe is fixed, and the lower half is connected to the cutting module and rotates in the pitch direction. By a torsion spring into this rotating part, the lower half pipe is closed and bridged to the hose after harvested tomato rolling down to the box. This hose is connected to the harvesting box, and the tomatoes are transported to the box while rolling by their own weight.

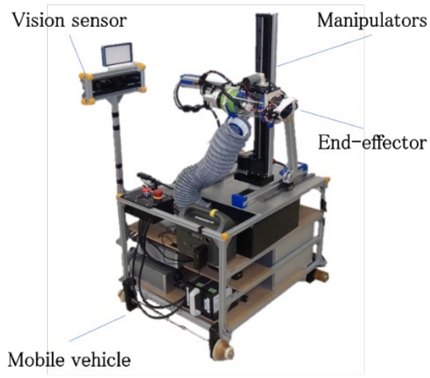


Fig. 1 The tomato harvesting robot for moving on the rail, which consists of mobile vehicle, vision system and a manipulator with an end-effector.

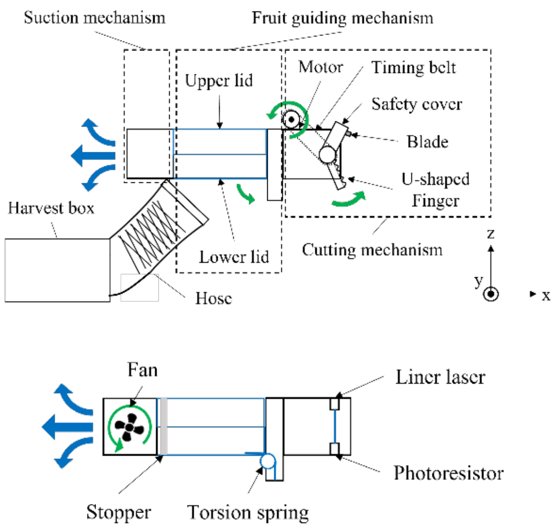


Fig. 2 The developed suction cutting type end-effector. The target tomato is absorbed using a fan, and the stem is cut.

2.3. *Harvesting Process*

The flow of harvesting is shown in Fig. 3. Firstly, a target tomato is absorbed by the suction mechanism (I). When the tomato goes into the cutting mechanism, the laser beam to the photoresistor is blocked, and the photoresistor detects the object and the robot recognize the tomato is in cutting position (II). If the grasp is successful, the U-shaped finger is rotated to cut the stalk (III). The tomato rolls over to the stopper of the fruit guiding mechanism. Then, the lower half of the pipe to open by the weight of the tomato , and the tomato goes into the hose (IV). The tomato rolls along the hose and enters to the harvest box. After the tomato dropped, the pipe is closed by the torsion spring (V). Conventional end-effectors did not have a fruit guiding mechanism, and harvested tomatoes were grasped in the cutting mechanism and transported by manipulator to the harvest box and dropping them [8]. Even if no damage was observed on the surface of the tomatoes, still there is a possibility of the inside deformation. The proposed fruit guiding mechanism uses a flexible hose and rolls the fruit diagonally, which will reduce the impact and prevents inside damages.

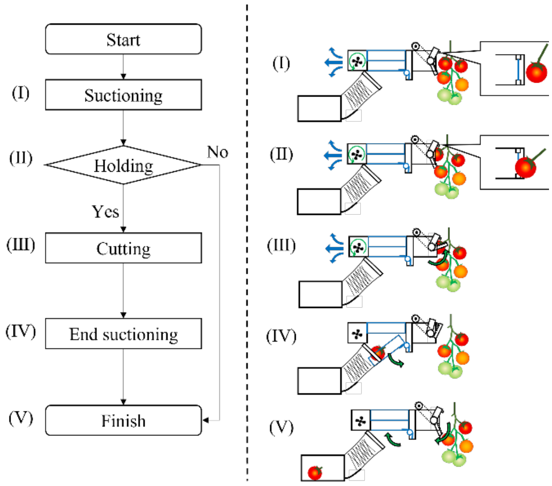


Fig.3 The process of tomato harvesting. The tomato is absorbed by air and the stem is cut when the tomato is in the right position, and roll over to the box.

2.4. *Threshold adjustment of photoresistor for tomato holding*

Whether a tomato is harvested or not is determined by the value of the photoresistor, however the photoresistor is affected by the brightness of the surrounding environment. Fig. 4 shows the results of measuring the photoresistor values indoors and outdoors. The x axis shows the time, and the y axis the sensor value at no object inside. As shown in Fig. 4(1), the photoresistor value is almost constant at around 840 in the indoor, while the value changes more than 150 between cloudy conditions (Fig. 4 (ii)) and direct sunlight (Fig. 4 (iii)) in outdoor. In this paper, we introduced the method to adjust the threshold value of the photoresistor after a constant period. Fig. 5 shows the result of setting the threshold value for the photoresistor value in Fig. 4. 10 times the value of the photoresistor is measured every 30[s] and the average is taken to get the current brightness. The threshold value is set by adding 100 to the value. The dashed line in Fig. 5 shows the threshold value, which is updated according to the value of the photoresistor.

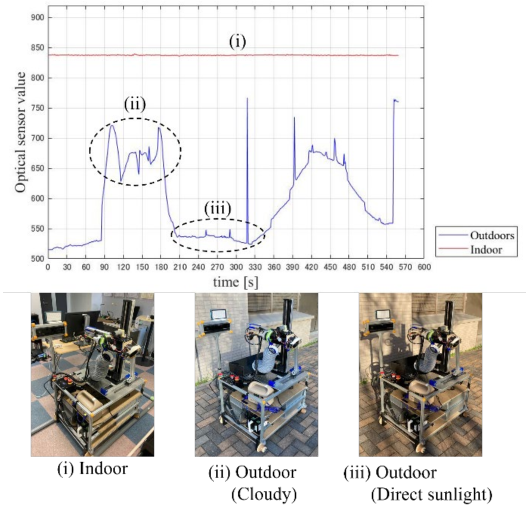


Fig. 4 The value of photoresistor to determine whether the tomato is in the right position for cutting when no object inside the cutting area exists.

3. Color consistency

3.1. *Polarizing films for camera and light*

In harvesting tomatoes, the proposed robot determines the maturity of tomato by the hue value of surface in the HSV color model whether the hue value is within a certain range of red, which is decided depending on the

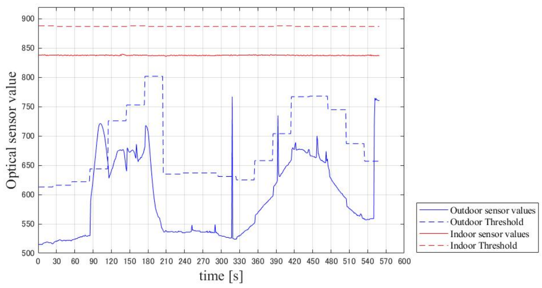


Fig. 5 The threshold is updated using previous stable sensor data to adapt the change of lighting condition.

condition of the market. In the greenhouse, due to the effects of sunlight, the color of the tomatoes appears different from their true color. If the entire image is darkened by clouds, the hue value is not calculated properly because of reduction of the color information. The vision system which can determine that "red" is red under sunlight is necessary, therefore, we conducted the evaluation experiments using a color map in our greenhouse.

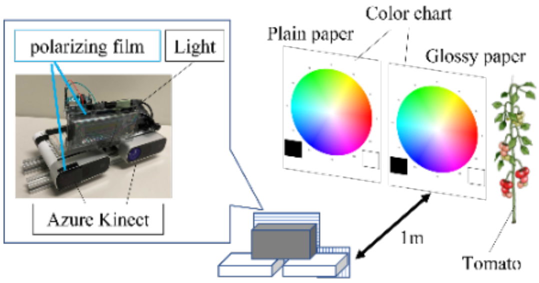
As shown in Fig. 6, a color map was set in the greenhouse and the transition of hue was recorded. As tomatoes have specular reflection on the surface with lighting on, there is a possibility that color information will be lost by white blur. To solve this problem, we used the polarizing films to attach them to one of the cameras and the light to be perpendicular to each other. Two cameras (Azure Kinect) were placed in parallel to compare the effects of polarizing film, and a light was placed above the cameras to compare the effects of light on and off with polarizing filter whose angle is perpendicular to that of camera.

3.2. *Evaluation experiments in greenhouse*

The images were taken every minute from 12:00 to 18:00. Figure 7 shows the relationship between the printed hue values and the measured hue values by comparing eight different conditions with paper type (plain or glossy), light (on or off), and polarizing film (with or without). Compared to the printed values (black line), the hue values around yellow show the differences, however, small differences in the different conditions. During the daytime, the results were similar for all time periods, and no significant changes were observed. As shown in Fig. 8, when the light was not turned on, the color information could not be observed after sunset, and it can be seen that the polarizing films reduce the specular reflection. This indicates that the lighting with the polarizing film is effective especially in dark environments such as after sunset.

4. Conclusion

In this paper, we described the problems of harvesting and recognizing tomatoes in the greenhouse. The suction cutting type end-effector can harvest tomatoes with less damaging them. Regarding color recognition, the effect of sunlight to brightness was found and the polarizing



(a) Experimental setup

(b) An example photo

Fig. 6 The experimental setup to measure the effects of sunlight. The polarizing films are attached to the one of camera and the light to be perpendicular to each other.

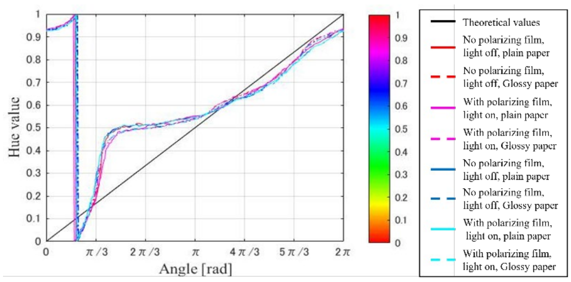


Fig. 7 Comparison of hue angle by measured values and printed values. The differences between polarizing films, lighting, paper types are compared.

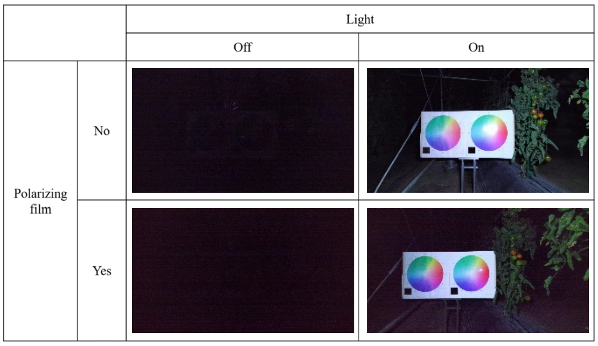


Fig. 8 The effect of polarizing films when the light is on. The reflection from surface is reduced by the films.

films will work effectively especially with the lighting devices.

of angle 90 [deg] is near the center of the aluminum foil, it is considered that it was generated by the combined wave of the ultrasonic array. The sound pressure of 0.2 [MPa] where cavitation occurs between 50 and 100 [mm] at every angle exceeded 0.2 [MPa], but in this experimental result, there is no holes or cracks.

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